Rapid Assessment of the Effectiveness of Engineered Off-Channel Habitats in the Southern Interior of British Columbia for Coho Salmon Production

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RAPID ASSESSMENT OF THE EFFECTIVENESS OF ENGINEERED OFF-CHANNEL HABITATS IN THE SOUTHERN INTERIOR OF BRITISH COLUMBIA FOR COHO SALMON PRODUCTION

by

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ABSTRACT

Cooperman, M.S., Hinch, S.G., Bennett, S., Quigley, J.T., Galbraith, R.V., and Branton M.A. 2006. Rapid Assessment of the Effectiveness of Engineered Off-Channel Habitats in the Southern Interior of British Columbia for Coho Salmon Production. Can. Manuscr. Rep. Fish. Aquat. Sci. 2768: v + 30 pgs.

Prior research has demonstrated that enhanced and constructed off-channels can provide high quality rearing habitat for young salmonids, particularly coho salmon, and provision of these habitats has become a common management action throughout western North America. However, detailed assessment of the functionality and fish use of these habitats has been limited. We used a rapid assessment approach to assess level of off-channel-mainstem connectivity, thermal suitability and juvenile coho salmon utilization of ten constructed off-channel projects in the greater Kamloops, British Columbia area. Eight of ten off-channels appeared to be functioning as designed, although five of these eight had conditions that may compromise their utility to young coho salmon. In particular, the presence of beaver dams and/or extensive aquatic macrophyte growth may limit connectivity to the parent system or impair water quality. While it appears engineered off-channels can, and in many cases do, provide significant benefits for young coho salmon rearing in the southern interior of BC, their effectiveness may be greatly enhanced by targeting construction to sites that provide upwelling groundwater and by making routine project maintenance a management priority. To ensure constructed off-channels provide long-term benefits, we suggest future funding allocations for off-channel construction explicitly incorporate resources for project monitoring and maintenance and that management agencies responsible for the off-channels continue and expand their efforts to recruit local community group stewardship.

RÉSUMÉ

Cooperman, M.S., Hinch, S.G., Bennett, S., Quigley, J.T., Galbraith, R.V., and Branton, M.A. 2006. Rapid Assessment of the Effectiveness of Engineered Off-Channel Habitats in the Southern Interior of British Columbia for Coho Salmon Production. Can. Manuscr. Rep. Fish. Aquat. Sci. 2768: v + 30 pgs.

Nous avons employé une approche d'évaluation rapide pour évaluer dix projets d'aménagement d'habitats hors chenal dans la région de Kamloops, Colombie-Britannique, au niveau de la connexité entre l'habitat hors chenal et le cours d'eau principal, de la qualité thermique de l'habitat, et de l'utilisation de ce dernier par les jeunes saumons coho. Huit des dix chenaux fonctionnaient apparemment tel que prévus, bien que cinq parmi ceux-ci présentaient des conditions pouvant potentiellement compromettre leur utilité pour les jeunes saumons coho. En particulier, la présence de barrages de castors et/ou la prolifération de macrophytes peut réduire la connexité du système ou encore la qualité de l'eau. Bien qu'il semble que les chenaux aménagés puissent procurer certains avantages pour les jeunes saumons coho dans la région du sud de l'intérieur de la C.-B., leur efficacité pourrait être largement accrue si l'entretien routinier des projets devenait une priorité des gestionnaires. Ainsi, nous suggérons que les allocations futures de fonds pour la construction d'habitats hors chenal incorporent explicitement les ressources nécessaires au suivi et à l'entretien des projets, et que les gestionnaires responsables des projets continuent d'épanouir leurs efforts pour assurer l'intendance de ces derniers par les groupes communautaires impliqués.

INTRODUCTION

Artificially constructed off-channels have been shown to provide high quality rearing habitats for young salmonids, particularly if they involve upwelling groundwater (Swales and Levings 1989, Bonnell 1991, Richards and Cernera 1992, Keeley et al. 1996, Bratty 1999, Giannico and Hinch 2003, Morley et al. 2005, Rosenfeld 2005). Based on a meta-analysis of published literature of coho salmon (Oncorhync*hus kisutch*) use of engineered off-channels, Rosenfeld (2005) found that small constructed ponds were more productive per m^2 than large constructed ponds, that during summer months lotic systems produced higher numbers and biomass of coho parr than did lentic systems per unit area, and, there were no discernable differences between lotic and lentic systems in the production of smolts on a per unit area basis. Because of the apparent benefits that artificial off-channels may have for restoring or enhancing salmonid populations, hundreds of thousands of dollars of provincial and federal funds have been spent on construction or enhancement of these habitats for the purpose of increasing salmon production in British Columbia (Rosenfeld 2005). Unfortunately, there has been limited effectiveness evaluation of these constructed off-channels (Rosenfeld 2005, Quigley and Harper 2006).

Herein, we report results of a rapid assessment of ten off-channels of the southern interior of British Columbia. These off-channels were constructed with the explicit purpose of enhancing adult coho salmon abundance via providing high quality rearing habitat for coho parr, a perceived limiting factor for coho production in the southern interior of British Columbia (Miles 1995, Burt and Wallis 1997). To assess the success of each project at attaining the goal of enhanced coho productivity, we addressed three topics: i. system hydrology and physical connectivity, ii. thermal suitability, and iii. coho utilization and growth. Specifically, our assessment addressed three broad questions, 1) does water move through the off-channel as intended, including maintenance of surface water connectivity to its parent water body and without barriers to movement between the off-channel and parent water; 2) does the off-channel provide suitable rearing temperatures for coho salmon throughout the summer and might the off-channel provide cold water refugia at times when parent waters approach the upper limit of coho tolerance; and 3) do coho salmon use the off-channel sites for rearing, and if so, what is their physical condition?

Based on a synthesis of each off-channels performance in the three categories above, we offer a summary interpretation of the relative success or failure of each project, and we discuss our results in terms of successful models for future replication and project maintenance needs.

To assist in identifying off-channels of similar characteristics, we classified each off-channel based on three, non-mutually exclusive, criteria: is the off-channel a wholly constructed system or an enhanced natural feature, is the off-channel surface water or ground water dominated, and is off-channel predominantly lentic or lotic (e.g., still or flowing water). We define "wholly constructed," to be sites that required extensive capital expense and engineering to create the off-channel, whereby "enhanced natural feature" is used synonymous with "project of opportunity," meaning a more modest effort was undertaken, typically in the form of re-establishing surface water connectivity

between an isolated off-channel habitat and its parent water body via digging a connecting channel.

METHODS

Physical connectivity

We visually assessed the level of connectivity between each off-channel and its parent water body by walking the full length of each off-channel project and its distributary channel. Primary observations included presence / absence of physical barriers such as dried channels or beaver dams and thermal barriers caused by stagnant or shallow water patches between the off-channel and mainstem habitat. Each off-channel project was visited a minimum of three times, when thermaloggers were deployed, the day of fish sampling, and when thermaloggers were collected.

Thermal regime

We deployed one thermalogger (Vemco© 12-bit miniloggers, one value per hour) in each of seven of the ten off-channels along with a 'mate' logger in the mainstem of receiving water bodies. Off-channel thermaloggers were positioned to capture a representative location in the off-channel, and all were placed on the bottom of the water channel. Mainstem thermaloggers were placed upstream of the off-channel confluence, along the edge of the channel, and if possible, in a location sheltered from the current of the channel (i.e., downstream of local obstructions to flow or within local eddies), as these locations are the most likely to have been used by rearing coho had off-channels not been available. The three off-channels not receiving thermaloggers were Davies (restricted access), Ianson and Juliet, both of which have been subjected to detailed temperature monitoring in the past (Bratty 1999, Bennett 2004). Thermaloggers were deployed the week of June 27 2005 and collected the week of September 19 2005.

Fish abundance

Between August 8 and 20 2005, we sampled the fish community in the off-channel using baited "Gee" style minnow traps. Each off-channel was sampled only one time. We partitioned each off-channel into three to seven zones based on visual assessment of habitat structure with the number of traps deployed per zone proportional to zone size (range 3-11 per zone; Figure 1). All traps were deployed between 8 am to 12 noon, within 3 m of shoreline, rested on the bottom and were collected after a two hour fishing period. We used a hand held temperature probe to collect a single water temperature value at ten cm below water surface within each fish sampling zone at the time of trap deployment. We assumed each trap effectively sampled 5 m^2 of bottom area and deployed traps to provide a minimum of 2.5 m open space between all traps. Bait was two grams of cured salmon roe in perforated 35 mm film canisters.

All collected fish were sedated with Metomidate (AquaCalm,© Snydel Inc., Vancouver, BC), and species and length of each fish was recorded. For the first 20 coho parr withdrawn from each trap, we also measured body depth at the clystrum, eye socket diameter, and wet mass. Eye diameter is a useful measurement because unlike most other body dimensions, it is developmentally fixed and therefore immune to the influence of the individuals' nutritional history (e.g., growth rate of eye diameter doesn't change

regardless if an individual is well fed or starving). As such, eye diameter serves as a correlate to age, and thereby provides a means of standardizing comparisons amongst individuals and populations. For example, the ratio of mass to eye diameter provides a measure of age specific mass (or growth), a strong fitness correlate.

All fish were revived in holding tanks prior to release back to the off-channel. At Juliet off-channel, mass of some fish was not recorded due to scale malfunction.

SITE DESCRIPTIONS & RESULTS

Provided below are location specific descriptions and results of coho salmon sampling. For simplicity, references to all Tables and Figures are detailed here and are not specifically referred to for each site. Table 1 provides coho catch statistics and mean length and mass measures for each off-channel. Table 2 provides zone specific catch statistics. Table 3 provides zone specific water temperatures at time of fish sample collection. Figure 1 provides a schematic of each off-channel depicting significant natural features and zone specific coho parr catch data. Figures 2 and 3 provide side by side box plots of lengths and mass:eye diameter ratio for each off-channel. Figure 4 provides a histogram of eye diameter for each off-channel. Figure 5 provides time series of water temperature for each off-channel thermalogger and the receiving water body, and Figure 6 depicts the relationship between zone specific water temperature and coho parr catch per unit effort.

Histograms of eye diameters (Figure 4) tend to show a small second modal peak at 6 mm, suggesting this eye diameter demarcates age-0 and age-1 coho parr.

• Adams River off-channel (aka Cottonwood off-channel).

The Adams River off-channel is a wholly constructed project involving the excavation of a paleo-channel of the Adam's River within Roderick Haig-Brown Provincial Park, near Salmon Arm, BC. In addition to any benefits provided to rearing coho salmon, the Adams off-channel is known to provide spawning habitat for a large number of sockeye and coho salmon.

The off-channel contains both lentic and lotic sections and both sections have abundant in-channel structure. The water source is exclusively groundwater and the receiving water body is Shuswap Lake. Although the off-channel is set in a heavily forested location, visual assessment suggests there are limited amounts of over-hanging terrestrial vegetation, particularly deciduous trees. Water temperatures in the channel consistently remained between 10.5 and 15 °C and did not display diel heating or cooling.

We deployed 24 Gee traps across six zones, with three zones in each the lotic and lentic segments, and collected a total of 199 coho salmon parr with more than 80% of the total catch occurring in zones 5 and 6. These two zones were in the still water portion and had the coldest water temperatures measured in the off-channel. Eight of the 96 coho for which eye diameter was measured had eye diameters of 6.0 mm or greater, suggesting approximately 9% of the coho parr in the off-channel were age-1 and the rest age-0. Relative to the other off-channels, the coho parr of Adams River off-channel were of roughly average length, mass, and mass:eye diameter ratio.

A beaver dam exists at the point where the ponded area enters the lotic distributary channel. At the time of our survey, water was percolating through and over-

topping the dam. Due to the timing of our site visit, we could not determine if the dam interferes with either coho fry entering the lotic section or the out-migration of parr upon smoltification. However, the Adams Lake Indian Band is routinely retained to remove the beaver dam during the fall spawning period and the off-channel is routinely back-flooded by Shuswap Lake each spring (S. Bennett, personal observation), suggesting the beaver dam is not a significant movement barrier during either time period.

• **Davies off-channel.**

The Davies off-channel is a combination of an enhanced natural feature and a wholly constructed pond and drains to the Salmon River. The off-channel starts where a natural pond, fed by over-land flow from a marshy area in the foothills of the surrounding mountains, was expanded and then connected to a second, artificial pond via a short surface water channel. As designed, the water of the second pond should flow along a surface distributary channel to the Salmon River. There are modest amounts of overhanging terrestrial vegetation and abundant in-channel structure and aquatic macrophyte growth in both ponds of the off-channel system.

The Davies off-channel appears to be a mixture of ground water and surface water supplies, but it was impossible to confirm either source during our survey. Surface water predominates in the off-channel only during spring freshet and ground water is estimated to provide roughly 80% of the water budget at other times of the year (S. Bennett, unpublished data). Water temperatures at the time of fish sampling ranged between 17.5 and 21.2 °C, which are above the optimal rearing temperature of 12 to 13 °C for juvenile coho (Weatherley and Gill 1995). Because water temperatures were recorded near shoreline, it is possible the deeper off-shore portions had cooler temperatures. Temperature of the Salmon River at the inflow of the off-channel was not measured, but temperature of the mainstem at the Fellhauer property, which is approximately 20 km upstream, was approximately 17 °C.

We deployed 46 Gee traps and captured 34 coho salmon parr, three of which had eye diameters > 6.0 mm suggesting approximately 9 % were age-1 fish. Greater then 90% of all coho were collected in the upper pond (zones 1, 2 and 3). Relative to other off-channels assessed, these fish tended to be amongst the largest and heaviest encountered.

Beavers are persistently damming the outflow of the upper pond and thereby causing a notable dewatering of the lower pond. The distibutary channel from the lower pond to the Salmon River was dry and heavily over-grown with weeds and grasses at the time of our survey, suggesting water does not regularly flow from the off-channel to the river. According to the property owner, when the beaver dam blocks the outlet of the upper pond, the water overflows the bank of the pond and reaches the Salmon River via unchannelized over-land flow. Fisheries and Oceans Canada and the Salmon River Watershed Round Table are currently investigating solutions to the beaver dam problem (S. Bennett, personal communication).

Despite the aforementioned beaver activity, the Davies off-channel system appears to provide high quality coho rearing habitat, as evidenced by the modest densities and good condition of the collected coho salmon.

- **Fellhauer off-channel.**

The Fellhauer off-channel is an enhanced natural feature where a marshy region of a cattle pasture, including an open water area, was excavated to improve water movement through the channel and to establish connection to the Salmon River. Water supply is ground water, via both natural seepage into the channel and pumping of water into the head of the channel. Water temperature was consistently near 12.5 °C while the Salmon River ranged between 13 and 24 °C. The water column was entirely covered with duck-weed (*Lemna* sp.), there was no measurable current, and the distributary channel lacked surface flow. Fish sampling, involving 31 Gee traps collected no fish but many leeches.

The functional problems of this off-channel are well known to the land owner and Fisheries and Oceans Canada, and solutions are being investigated.

- **Ianson off-channel.**

The Ianson channel is an engineered lotic system although it has two small portions of still water habitat (zones 5 and 6). The off-channel drains to Lemieux Creek and has been subjected to intensive study in the past with the conclusion the Ianson channel provided high quality summer and winter habitat for young salmonids (Bratty 1999). The Ianson Channel has been used by the local fish hatchery as a smolt imprinting pond, also reflecting its high quality habitat. Thermaloggers were not deployed in the Ianson Channel, but water temperatures at the time of fish sampling ranged between 12.3 and 13.7 °C.

We collected 378 coho salmon parr in 20 Gee traps, with the majority of fish collected from lotic potions of the off-channel. Parr in the Ianson channel tended to have the smallest mean sizes and masses of the ten off-channel samples, although the differences between Ianson coho and other sites were not large. Based on eye diameter, approximately 4% of coho were age-1.

- **Juliet Creek off-channel.**

The Juliet off-channel is an engineered lotic groundwater system emptying into the Coldwater River. It has been intensively studied in the past (Swales and Levings 1989, Bennett 2004) and appears to provide exceptional coho rearing habitat. Water temperatures at the time of fish sampling ranged between 8.3 and 10.2 °C.

We collected 507 coho parr in 27 traps, with coho being present in all zones, although abundances were lowest in the zones with the coldest water. Length and mass of the coho tended to be near the average of the other off-channels evaluated. Approximately 9% of the coho measured had eye diameters > 6 mm suggesting they were age-1. Zone 3, an area characterized by artificial riffles, yielded a mean catch per unit effort of only 4.3 coho per trap, compared to zones 2 and 4, which lacked riffles, yielding 31.5 and 47.5 coho per trap.

- **Laperier off-channel.**

The Laperier off-channel is an enhanced natural feature, where a floodplain pond that had been historically isolated from the mainstem of the Salmon River was reconnected by digging inlet and outlet channels. The off-channel is a surface water system where in-flow is drawn from the Salmon River via a head-gate, and as such water

temperatures in the off-channel are equivalent to the mainstem. Between mid-July and mid-August, water temperatures at 3 pm were typically near 20 °C.

The off-channel has been used by local hatcheries as a smolt imprinting pond, suggesting it meets the habitat requirements of large numbers of fishes, although it is not clear if hatchery fish are present during the high temperature period or if they are introduced after temperatures moderate. At the time of our survey, the head-gate was fully open and the off-channel was flowing with a current comparable to the mainstem, suggesting slack water habitat may be limited. However, there is ample in-channel structure in the upper lobe of the complex plus abundant aquatic weed growth throughout, suggesting water velocities are not limiting to young coho. Twenty-six Gee traps collected five rainbow trout, one chinook salmon parr, and two coho salmon parr. The coho were of average length and mass relative to those collected in the other sampled off-channels.

- **Raft River off-channel.**

The Raft River off-channel is a constructed, predominately lentic, system that was constructed several years prior to the other off-channels in this evaluation. The project sits inside a meander loop of the Raft River and was designed to draw water from the mainstem of the Raft River via a culvert. However, the culvert sits in a depositional area along the inside bank of the meander bend, resulting in blockage by sediment accumulation. Despite the blocked inflow, the off-channel remains wet year-round, probably due to ground water upwelling. Water temperatures at the thermalogger, located near the clogged water intake pipe and at the upstream end of the off-channel, remained below 15°C throughout the study period and there was limited evidence of diel heating.

Large beaver dams block the two outlets of the off-channel. However, according to the property owner, the Raft River will establish surface water connections with the off-channel during high water events via over-topping of the beaver dams, indicating some level of connectivity exists and therefore salmonids may have sporadic opportunity to enter and exit the off-channel.

Twenty-five Gee traps collected 3 coho parr, which were slightly larger and heavier than average. All three had eye diameters < 6 mm suggesting they were age-0.

- **Ruechel off-channel (aka Lawson Creek).**

This ground water fed lotic system is a tributary to Duteau Creek near the town of Lumby and originated when approximately 1000 m of Lawson Creek was diverted off of the Quesnel Company lumbar yard to run alongside rail road tracks at the edge of the property. Large quantities of boulders and large wood, and concrete undercut banks were added to the channel in 1997. These features combined with naturally occurring watercress (*Nasturtium* sp.) growth within the channel, yields extensive structural complexity. At the time of our visit a beaver dam dissected the channel between zones 4 and 5 and appeared to be significant enough to prevent the movement of fish from upper to lower segments of the channel.

We collected 15 coho parr in 20 Gee traps, and the parr were of larger than average length and mass. Only one individual had an eye diameter > 6mm, suggesting a low abundance of age-1 coho.

Fish sampling occurred on August 15 and the thermalogger was collected on September 20. On the earlier date, there was abundant watercress growth within the channel but ample open water patches to provide holding locations for young fish. On the later date, the channel was entirely overgrown with watercress and visual assessment found no patches of open water in the channel. The high abundance of watercress may compromise habitat quality for coho parr during the later stages of the annual growing season and/or during the spring via dissolved oxygen sags associated with watercress respiration and decomposition and/or via interference with coho parr visual foraging. However, the magnitude and mechanisms of potential watercress impact were not investigated.

- **Senn Creek Oxbow off-channel.**

The Senn Creek off-channel is an enhanced natural feature, where an ox-bow lake and its in-flowing tributary were re-connected to the Eagle River, thereby allowing adult salmon to enter and pass through the oxbow lake for spawning in Senn Creek. Progeny can then rear in either the creek or the oxbow lake. In the first year after opening the Senn Creek system to the Eagle River, a few dozen adult coho spawned within the system (S. Bennett, unpublished data). In the half dozen years since construction the number of spawning adult coho using the Senn Creek system has increased to approximately 1,500 (S. Bennett, unpublished data).

The temperature time series should be interpreted with caution, as there is reason to suspect the thermalogger was exposed to the air for a period of time caused by a falling water level in the off-channel system. Despite the falling water levels, it appears that connectivity between the two lobes of the oxbow, and therefore the entry and exit points of the system, maintain year-round connectivity. Due to its inaccessibility, we did not have opportunity to inspect the outflow channel for barriers to movement.

Our fish sampling deployed 44 Gee traps and collected 18 coho parr, which tended to have smaller lengths and masses than average, although mass:eye diameter was largely similar to those observed in other off-channels. None of these coho had eye diameters > 6mm. We captured the majority of the coho in Zone 7 of the off-channel, which is the channel connecting the two lobes of the oxbow lake, not along the shoreline of the still water areas. Past fish sampling efforts collected large numbers of young coho in the off-shore portions of both pond lobes (S. Bennett, unpublished data), an area we did not sample.

- **Tito Beaver pond off-channel.**

The Tito Beaver pond off-channel is an enhanced natural feature, where an isolated beaver pond was connected to the Eagle River system via attachment to Tito Creek. Ground water upwelling appears to account for the beaver pond remaining inundated year round despite limited surface water inputs, but the specific hydrology of the system could not be determined. Water temperature in the system consistently remained suitable for young coho, ranging between 10 and 15 ^{o}C, and habitat structure appears well suited for young coho. However, at the time of our fish survey there was no surface water connectivity between the beaver pond and Tito Creek because a beaver dam blocked the outflow of the beaver pond off-channel.

We deployed 20 Gee traps around the perimeter of the beaver pond and in the inflow channel, but collected only one coho. This individual was amongst the largest coho observed during the entire study (fork length 79.0 mm, mass 4.98 gr, eye diameter 6.19 mm).

DISCUSSION

We focused our off-channel effectiveness evaluation on two issues, system functionality and juvenile coho salmon utilization. System functionality incorporates considerations of hydrology (e.g., is water entering and moving through an off-channel as desired?), connectivity (e.g., does an off-channel maintain a surface water connection to the mainstem river?), and thermal suitability (e.g., are water temperatures within the acceptable and/or optimal range for coho parr and how do water temperatures compare to the receiving mainstem river?). Coho utilization was evaluated based on abundances and measures of individual condition such as length and weight.

In total, eight of the ten evaluated off-channels appeared to be functioning as designed, although five of these eight had conditions that may compromise their utility to young coho salmon. The two "non-functional" off-channels, the Raft River project and the Fellhauer project, both suffer from significant problems in site hydrology and are unlikely to be corrected in the near future, though solutions to the problems are presently being investigated by the Habitat Management Unit of Fisheries and Oceans Canada. Both of the non-functional projects were constructed prior to formation of the current Fisheries and Oceans BC Southern Interior Habitat Management Unit and were "inherited" by this group.

Based on the abundance and condition of coho salmon coupled with no apparent physical barriers hindering movement between off-channel and parent water body, three off-channel projects we evaluated appeared to be functioning very well without any perceived short-comings. The Ianson and Juliet off-channels supported large numbers of young coho and all fish appeared to be in good condition, although those of the Ianson Channel tended to be amongst the smallest observed in this study. The Senn Creek Oxbow project was the one "enhanced natural feature" that appeared to function as designed and provide good coho salmon productivity benefits.

In almost all regards, the Adams River off-channel merits lumping with the above off-channels as a fourth significant positive habitat for coho salmon. However, presence of a robust beaver dam between the ponded water portion, where most of the coho salmon were located, and the distributary channel that links the ponded area to Shuswap Lake and the Fraser River system calls into question the contribution the parr above the dam may make to the eventual number of returning adults, as it is unclear whether or not parr above the beaver dam are able to exit the off-channel once they initiate the smoltification process. However, three independent fisheries evaluations of the Adams off-channel from past years also found high densities of young coho in the lentic portion of the system (S. Bennett, unpublished data), suggesting one of three explanations: i) the beaver dam has only recently emerged as a deleterious impact to fish movement, ii) despite any impact from the dam, sufficient numbers of adult coho consistently return to the Adams channel to seed the lentic portion with progeny, iii) seasonal back-water effects from Shuswap Lake coupled with dam removal by the local First Nations Band

renders the dam inconsequential. Regardless of the magnitude of impact the dam may have on coho production, a long-term solution to the beaver problem appears warranted and may be as simple as expanding the frequency of dam removal efforts to the additional times when coho are entering and exiting the off-channel. Furthermore, this case study illustrates the need for routine programmatic effectiveness monitoring as it provides an example of how conditions can change over time and suggests the value of routine inspection.

Analysis of growth patterns of juvenile coho salmon using scales collected from southern interior off-channels in past years concluded that individuals larger than 75 mm FL were age-1 (S. Bennett, unpublished data). Based on this criterion, 12.0% of the coho we measured during this off-channel assessment were age-1. Our aging estimates based on eye diameters suggested diameters greater than 6.0 mm equated to age-1 coho, and this criterion indicted that 9.5% of the coho measured were age-1, suggesting the two aging methods yielded comparable results. As such, eye diameter may be a useful tool for rapid assessment of age distribution of juvenile coho salmon in this region.

The lower percentage of age-1 fish present in Ianson Channel relative to other off-channels (4% assumed age-1 compared to the more common value of 9% assumed age-1) suggests either a greater percentage of Ianson Channel coho outmigrate as age-0 smolt or that over-winter survival of age-0 parr is poor. The steady supply of ground water inflow to Ianson Channel suggests it is unlikely that winter temperatures or oxygen deficit would be a limiting factor to coho survival, and Bratty (1999) suggested the Ianson Channel may provide above average over-wintering conditions for young coho. Regardless, either explanation for the relative paucity of age-1 coho may explain the smaller mean size and mass of Ianson coho.

Perhaps not surprisingly, the Juliet, Ianson and Adams sites share many features, including being wholly constructed, predominantly lotic systems with reliable ground water inflow. Not-with-standing the realization that good coho parr production does not necessarily equate with improved adult returns, these systems appear to provide a good ecological model for replication in the southern interior of British Columbia. It is curious to note that two of these four well performing off-channels had limited amounts of zero velocity habitat available, despite the widely held belief young coho prefer low velocity habitats (Bisson et al. 1988, Bjornn and Reiser 1991, Nielsen 1992, Grand 1997). Coupled with Senn Creeks high catch rate in Zone 7, the one area with measurable current within the Senn Oxbow off-channel, it is unclear if juvenile coho of the southern interior are benefiting from flowing water within the off-channels or if this observation is simply a function of the sites investigated. Although not explicitly measured, the water velocities in each of these lotic off-channels were not very fast and there was abundant in-channel structure to create low velocity areas. Further, presence of some current may be a benefit to young coho, as enhanced production of aquatic invertebrates and/or delivery of food items via the drift can be energetically advantageous (Rosenfeld 2005). This same argument suggests that, despite the low local abundance of coho near the artificial riffles of Juliet off-channel zone 3, riffles may have a positive benefit for the system as a whole. Future studies addressing the relative value and optimal mixtures of water speeds and velocities within off-channels would be useful.

Reports that coho parr catch rates were highest in the off-shore portions of the Senn Cr. oxbow (S. Bennett, unpublished data) is unusual in that the majority of

published reports on young coho habitat selection indicate a strong preference for remaining near shore, perhaps due to the benefits of over-head protection plus terrestrial invertebrate inputs associated with over-hanging riparian vegetation (Swales and Levings 1989 and citations therein). If this off-shore behaviour in the Senn off-channel is frequent, it could explain our relatively low catch, as our traps were placed near the shoreline. Cooler water and/or greater depths in the off-shore areas of the pond may account for such off-shore distribution.

Two off-channels assessed appeared to be providing coho rearing benefits based on our one day rapid fish assessments, although site specific considerations may prevent them from reaching their maximal effectiveness. It is evident that young coho enter the Ruechel off-channel and that for at least a portion of the growing season the channel provides suitable habitat. However, the ultimate fate of Ruechel coho remains unknown and further investigations are needed to determine if extensive watercress growth renders the Ruechel off-channel unsuitable late in the growing season or in the spring, and if so, whether or not Duteau Creek provides acceptable conditions for emigrating coho parr. Meanwhile, the Davies off-channel of the Salmon River system supported modest numbers of relatively large coho parr, but the connectivity of the off-channel to the mainstem of the Salmon River and the hydrology of the lower pond, and therefore the rearing capacity of the off-channel project, may be negatively impacted by beaver activity. Provided access and water flow limitations are addressed via excluding beaver from the outlet of the upper pool, the exceptional size and weight of the Davies off-channel coho suggests this site could support even greater abundances of rearing coho. Despite both of these off-channels supporting reasonable numbers of coho parr at the time of our surveys, there appears to be opportunities for the sites to be even more productive.

The Laperier off-channel appeared to be functioning as designed, but it appears to be under-utilized by naturally produced coho parr while abundances of hatchery produced coho can be high, depending upon the timing of hatchery releases (S. Bennett, personal observation). Although beyond the scope of this report, it seems likely that the limited abundance of naturally produced coho salmon in the Laperier off-channel may be related to low abundance of adult spawners in the local reaches of the Salmon River (Burt and Wallis 1997, Society 2004) and the resulting low supply of recruits into the off-channel. Given that two coho salmon parr of average size and mass were collected within this off-channel, and that adequate physical habitat appears to be available, it may be possible to expand the role of the Laperier off-channel in local population enhancement efforts, providing summer-time water temperatures in the mainstem of the Salmon River do not exceed the lethal limit for coho salmon.

The three remaining off-channels assessed in this effort, Tito, Raft and Fellhauer, appear to have failed at providing benefits to juvenile coho salmon during our evaluation period, although the Tito beaver pond has obvious potential should connectivity with the mainstem waterways be provided and maintained, and this effort is anticipated in the near future. The other two sites had significant hydraulic limitations to their effectiveness, and it is uncertain how or if these problems could be remedied. However, both systems, particularly the Raft River off-channel, seem to provide adequate physical habitat and suitable water temperatures and therefore probably could provide juvenile coho benefits should the hydrologic short-comings be remedied.

Because our site-specific observations stem from only a single day at each of the study sites, all during summer low water conditions, we can not fully evaluate the true long-term effectiveness of the engineered habitats or the true impacts of the highlighted site-specific potential short-comings such as beaver dams, dry distributary channels or excessive aquatic macrophyte growth. Also, we can not claim high confidence that our fish sampling results are accurate or precise measures of fish use of the off-channels. Site conditions change daily, seasonally, and annually, and low fish capture rates on one day may not be a true reflection of fish utilization as weather and other factors may affect fish behaviour, and therefore catchability. Similarly, beaver dams that are a movement barrier at low flow may not be barriers at higher water levels. As such, our observations are useful as a snap-shot in time and as a sampling of the successes and issues associated with the 'at-large' population of engineered off-channels, but our data do not necessarily capture the full range of issues associated with how these habitats function or are used by fish.

Our case studies illustrate the need for continuing effectiveness monitoring, as it is only via systematic evaluation that potential limiting factors can be identified and remedied. For example, it is evident that beavers represent a significant hurdle to the long term functionality of many of these sites as 50% of the evaluated projects had dams present, often in locations that compromised connectivity of off-channels to mainstems. At a minimum, breaching beaver dams at the time of significant coho salmon life history events, such as swim-up and smoltification, could reduce the impact of dams on coho salmon fisheries benefits stemming from off-channel projects. Based on the success of past cooperative efforts amongst Fisheries and Oceans Canada, First Nation bands, watershed round tables and private land owners, it appears important to continue to foster and establish long-term partnership commitments for project maintenance. Explicitly incorporating annual maintenance and monitoring needs during the budget planning stage of future off-channel development projects could significantly help in assessments of project effectiveness and adaptive management (Reeve et al. 2006).

In synthesizing the results from our rapid evaluation of these ten off-channel case studies, groundwater dominated systems appear to have provided the greatest juvenile coho salmon rearing benefits. Although it is impossible to determine from our data if the benefits of ground water inputs accrue solely from colder water temperatures during the summer (Figure 6), or other differences including warmer temperatures during the winter (Bratty 1999), increased food productivity (Giannico and Hinch, *in press*), or the fortunate absence of beaver dams, our results suggest that targeting any future off-channel construction efforts on locations that provide groundwater would be beneficial. Multiple other researchers have also commented on the benefits of groundwater inputs to off-channel habitats for coho salmon rearing in British Columbia (Swales and Levings 1989, Bratty 1999, Decker and Hinch 2002, Giannico and Hinch 2003).

ACKNOWLEDGEMENTS

Financial and logistic support was provided from several sources: the Southern Endowment Fund of the Pacific Salmon Commission, Fisheries and Oceans Canada Kamloops BC, Fisheries and Oceans Canada Vancouver BC, and the Natural Sciences and Engineering Research Council of Canada. Arianna Westergard provided invaluable field assistance, and Murray Manson and Jordan Rosenfeld provided insightful discussion and comments on drafts of this document.

Table 1. Mean catch per trap (standard deviation), mean length (standard error) and mean mass (standard error) for juvenile coho salmon captured in Gee traps set in constructed off-channel habitats in the Kamloops region. Not all coho collected were used in determining mean length and mass.

Site	# Traps	# coho collected	coho trap^{-1} Mean (st dev)	Mean Length (mm)	Mean Mass (grams)
Adams River	24	199	8.3 (12.1)	60.0 (0.54)	2.4 (0.06)
Davies	46	34	0.8 (1.7)	65.3 (1.10)	3.8 (0.21)
Fellhauer	31	0	0.0 (0.0)	--	--
Ianson	20	378	18.9 (21.1)	55.0 (0.67)	1.9 (0.08)
Juliet Creek	27	507	18.8 (23.2)	59.8 (0.85)	2.8 (0.17)
Laperier	26	2	0.1 (0.3)	61.7 (0.33)	2.8 (0.12)
Raft River	25	3	0.1 (0.3)	65.0 (4.00)	3.3 (0.56)
Ruechel	20	15	0.8 (1.4)	64.8 (2.30)	3.4 (0.34)
Senn Cr. Oxbow	44	18	0.4 (1.5)	55.3 (1.73)	2.1 (0.21)
Tito beaver pond	20	1	0.1 (0.2)	79.0 (na)	4.98 (na)

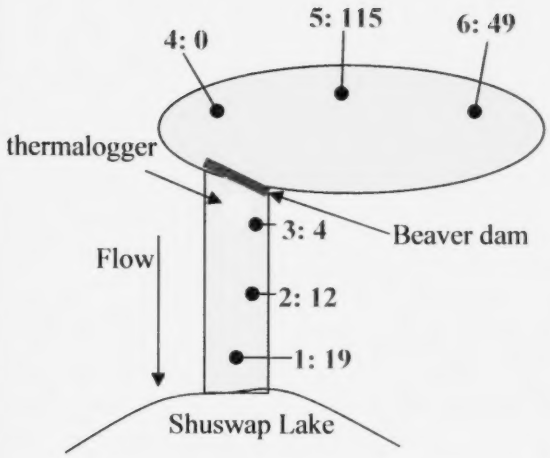
Table 2. Ratios of number of traps deployed to mean number of juvenile coho captured per trap (1 standard deviation), partitioned by zones within each site, based on captures in off-channel projects in the Kamloops region. Locations of zones are provided in Figure 1. Dashes (--) mean that zone did not exist at that site.

	Zone						
Site	1	2	3	4	5	6	7
Adams River	4: 4.8 (7.5)	4: 3.0 (4.2)	4: 1.0 (.8)	4: 0.0 (0.0)	4: 28.8 (12.0)	4: 12.3 (10.3)	--
Davies	11: 0.6 (1.5)	10: 2.4 (2.5)	7: 0.1 (0.4)	8: 0.4 (0.7)	--	--	--
Fellhauer	10: 0.0 (0.0)	11: 0.0 (0.0)	10: 0.0 (0.0)	--	--	--	--
Ianson	4: 6.0 (2.5)	4: 43.3 (27.5)	4: 12.3 (15.4)	4: 30.5 (18.2)	4: 2.5 (4.4)	3: 0 (0.0)	--
Juliet Creek	4: 25.3 (30.3)	4: 31.5 (24.7)	4: 4.3 (5.3)	4: 47.5 (27.2)	4: 14.0 (5.0)	4: 1.8 (3.5)	3: 3.7 (5.5)
Laperier	10: 0.2 (.42)	5: 0.0 (0.0)	4: 0.0 (0.0)	7: 0.0 (0.0)	--	--	--
Raft River	5: 0.0 (0.0)	5: 0.2 (0.5)	5: 0.2 (0.5)	5: 0.2 (.5)	5: 0.0 (0.0)	--	--
Ruechel	4: 1.8 (1.5)	4: 0.3 (0.5)	4: 0.5 (0.6)	4: 1.3 (2.5)	4: 0.0 (0.0)	--	--
Senn Cr. Oxbow	6: 0.5 (1.2)	7: 0.3 (0.5)	6: 0.0 (0.0)	7: 0.3 (0.5)	7: 0.0 (0.0)	4: 0.0 (0.0)	7: 1.6 (3.3)
Tito beaver pond	4: 0.0 (0.0)	4: 0.0 (0.0)	4: 0.3 (0.5)	4: 0.0 (0.0)	4: 0.0 (0.0)	--	--

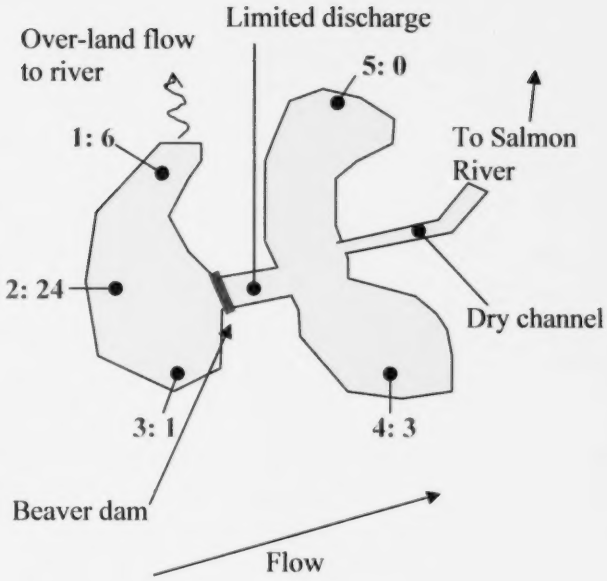
Table 3. Water temperature (°C) at the time of fish collection in each sample zone in ten constructed off-channels. Temperatures are from a single data value collected with a handheld temperature probe. NA = data not available, dashes (--) mean that zone did not exist at that site.

	Zone						
Site	1	2	3	4	5	6	7
Adams River	14.9	15.7	13.3	16.7	10.8	11.1	--
Davies	17.7	17.5	17.8	21.2	21.2	--	--
Fellhauer	--	--	--	--	--	--	--
Ianson	13.7	13.5	12.7	12.3	12.7	NA	--
Juliet Creek	10.2	10.2	9.8	9.4	9.3	8.5	8.3
Laperier	NA	NA	NA	NA	--	--	--
Raft River	12.4	NA	16.7	16.5	16.1	--	--
Ruechel	12.3	12.1	NA	NA	NA	--	--
Senn Cr. Oxbow	17.1	17.3	17.9	20.5	21.1	NA	NA
Tito beaver pond	15.7	15.3	15.3	15.8	16.5	--	--

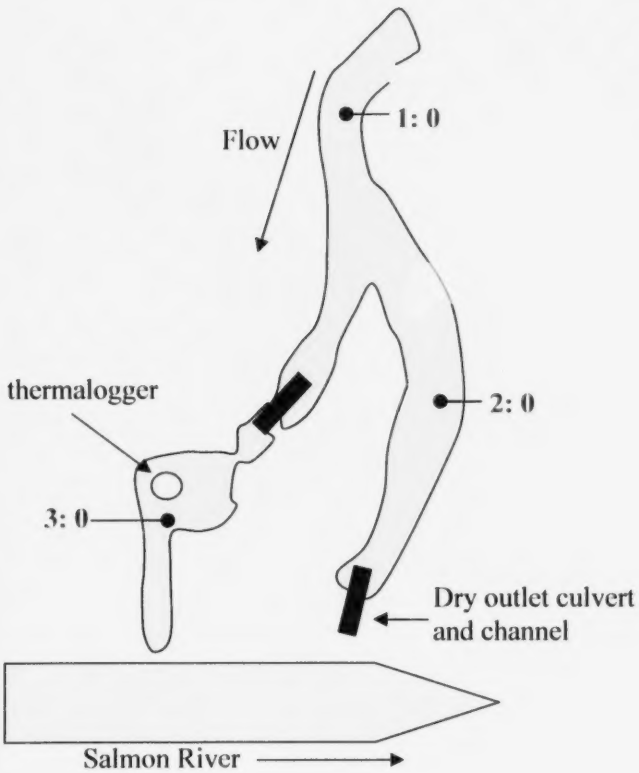
Figure 1. Schematic drawings of the 10 off-channel projects depicting salient natural features, fish sampling zones, number of coho captured in each zone and position of thermaloggers. Zone and catch data are presented as Zone # : # Coho collected in that zone. Figures are not to scale.



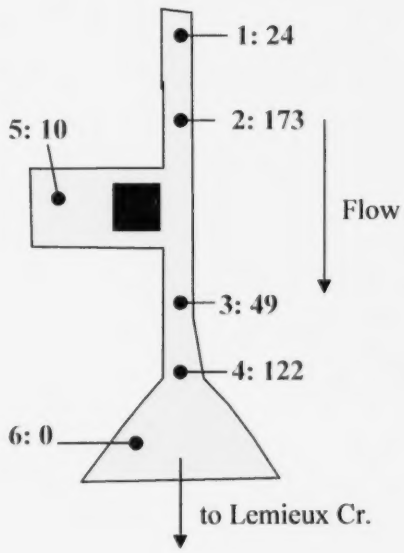
• **Adams River off-channel.**



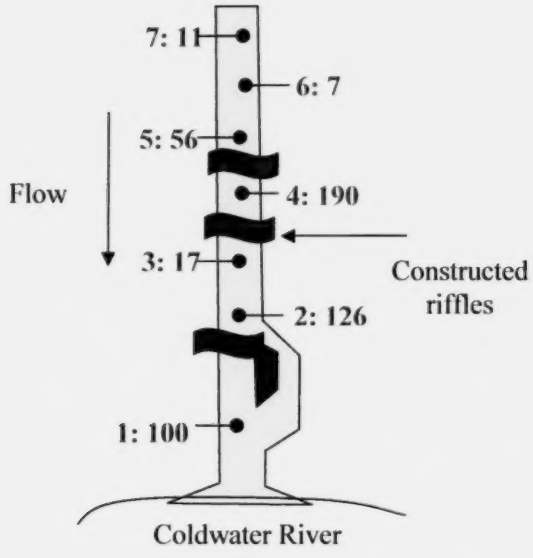
• **Davies off-channel.**



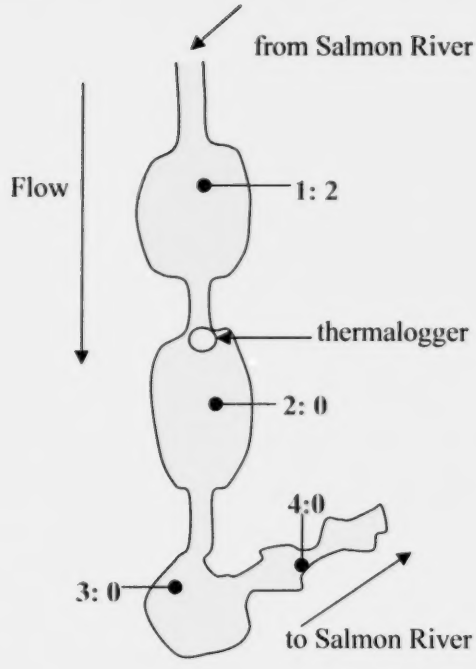
• **Fellhauer off-channel.**



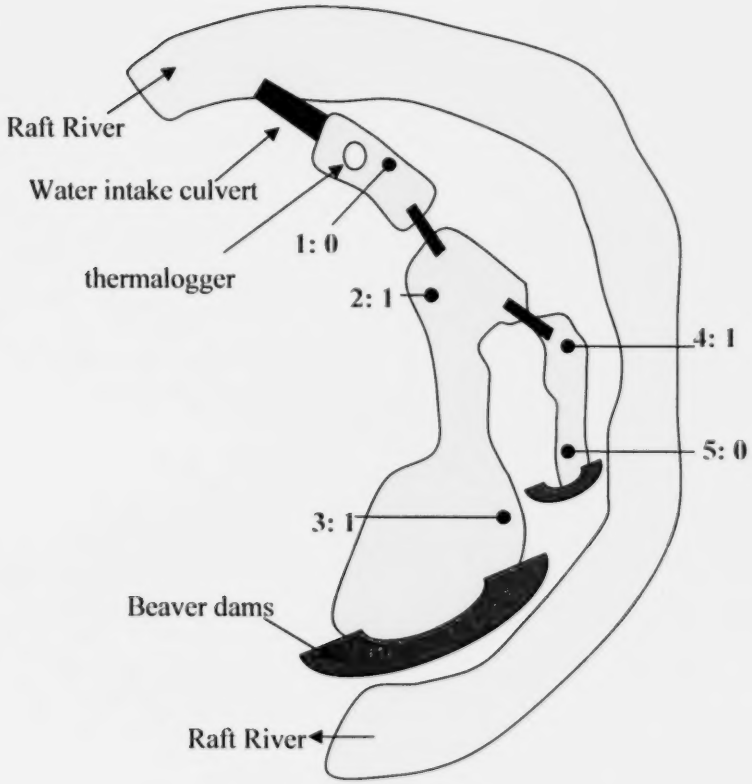
• **Ianson off-channel.**



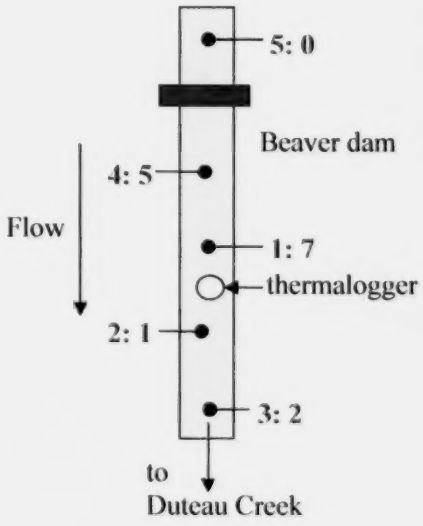
• **Juliet off-channel.**



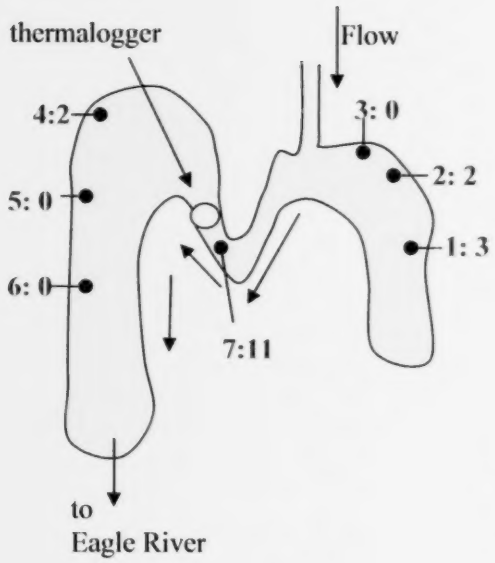
• **Laperier off-channel.**



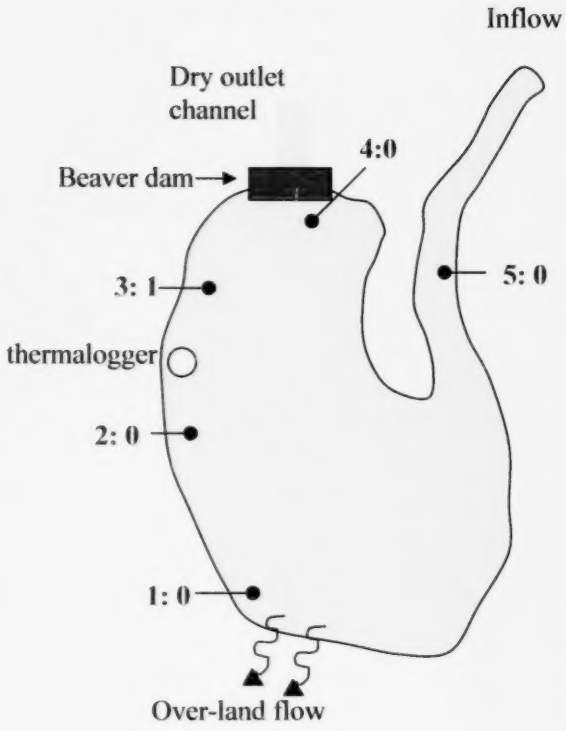
• **Raft River off-channel.**



• **Ruechel off-channel.**



• **Senn Cr. Oxbow off-channel**



• **Tito Beaver Pond off-channel.**

Figure 2. Box plots of fork lengths of coho salmon in selected man-made off-channels of the southern interior of British Columbia. The box contains the 25^{th} – 75^{th} percentile of data, the central line is the median value, lower and upper whiskers mark the 10^{th} and 90^{th} percentiles, and data points are individual cases outside the 10^{th}-90^{th} percentiles. Numbers along the x-axis provide the number of individuals used in computing the summary statistics.

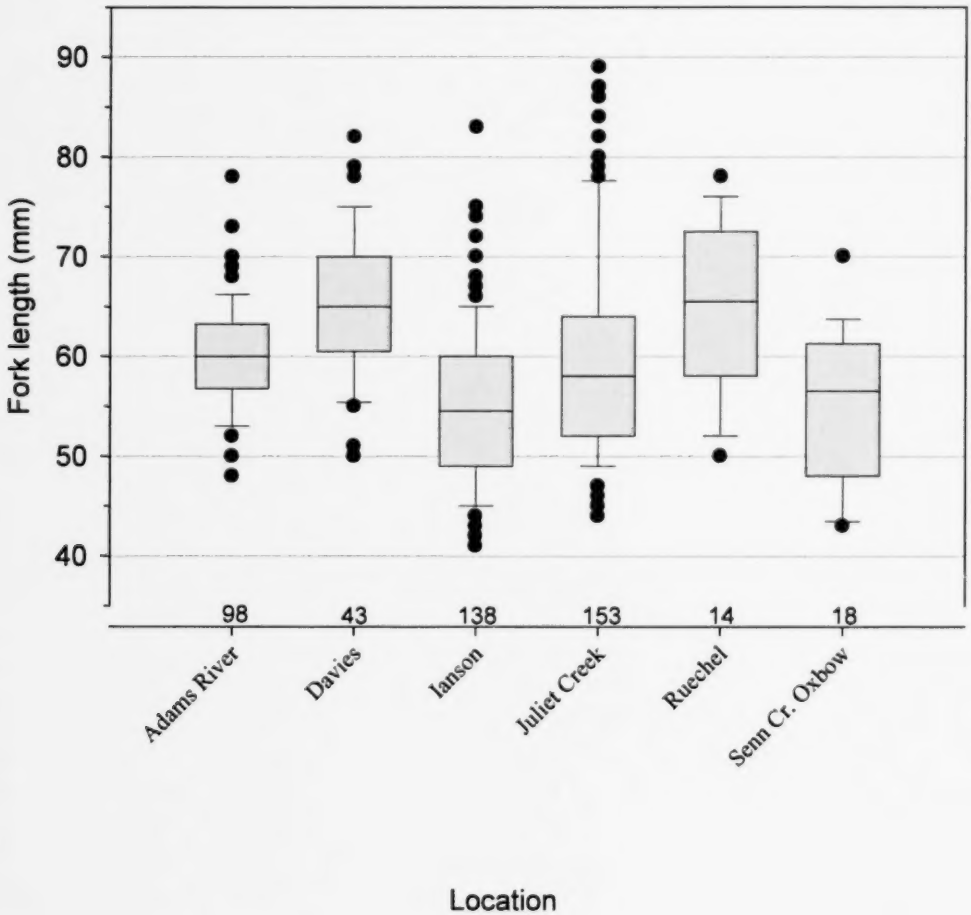


Figure 3. Ratio of wet mass to eye diameter for coho salmon parr collected from selected man-made off-channel habitats in the southern interior of British Columbia. The box contains the 25^{th} – 75^{th} percentile of data, the central line is the median value, lower and upper whiskers mark the 10^{th} and 90^{th} percentiles, and data points are individual cases outside the 10^{th}-90^{th} percentiles. Numbers along the x-axis provide the number of individuals used in computing the summary statistics.

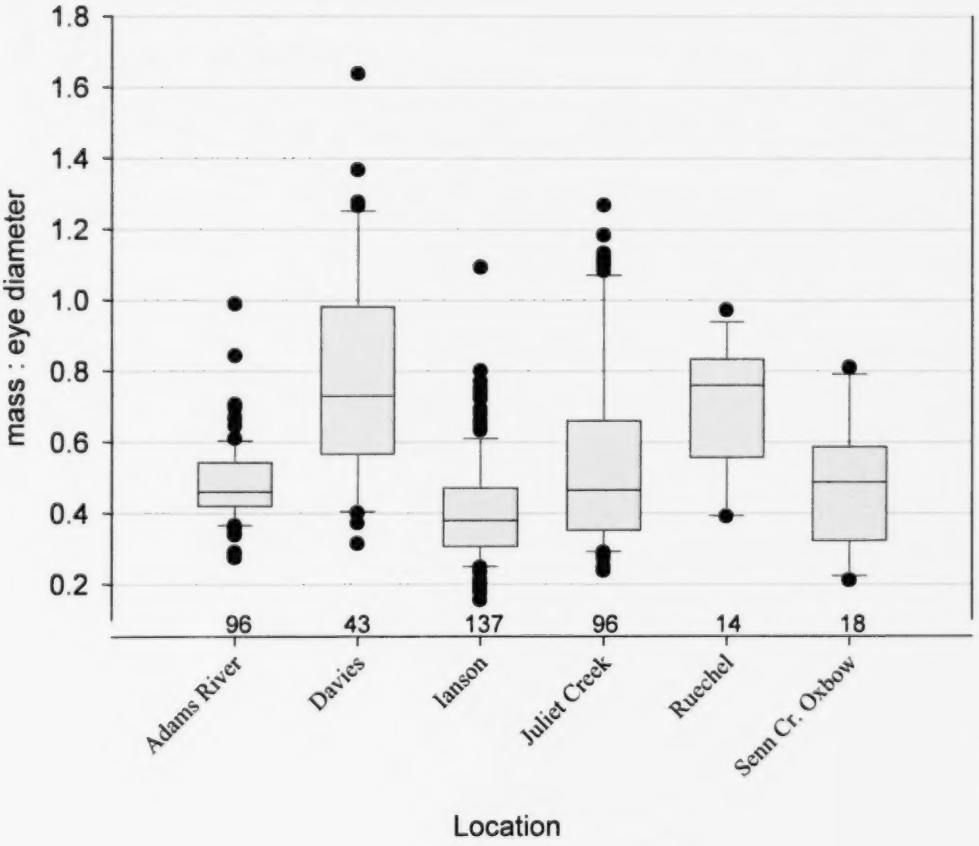


Figure 4. Histograms of eye diameter for selected off-channels. Based on distribution patterns, we estimate that an eye diameter of 6 mm or greater represents an age-1 coho.

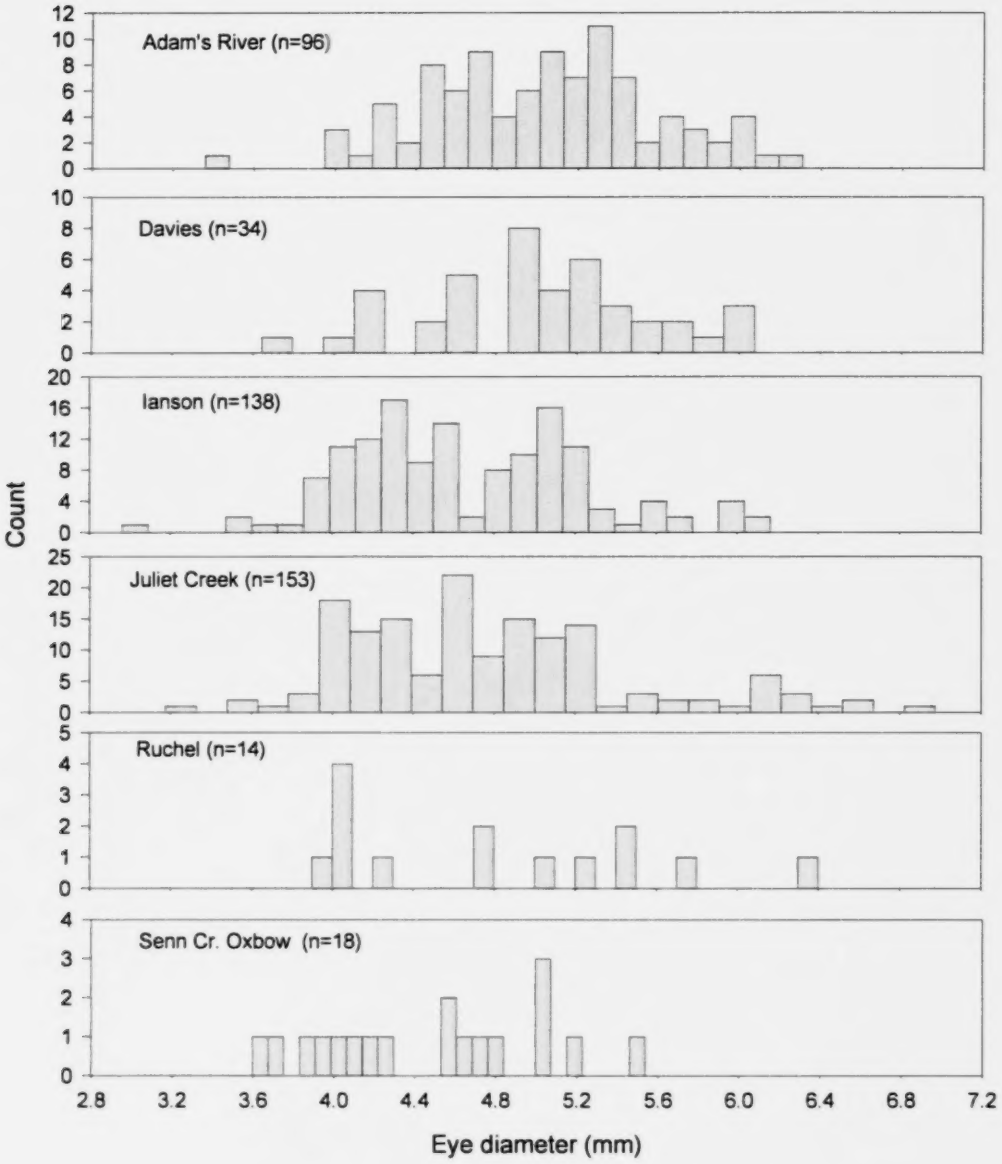
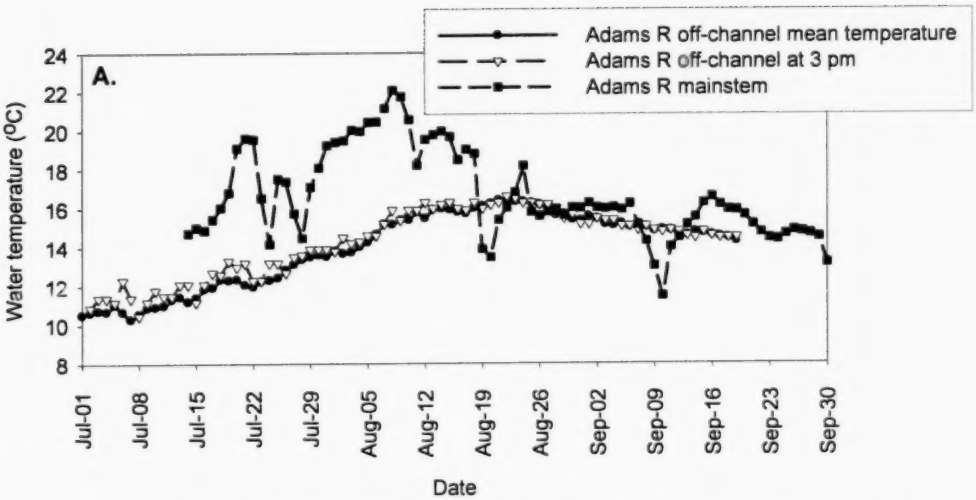
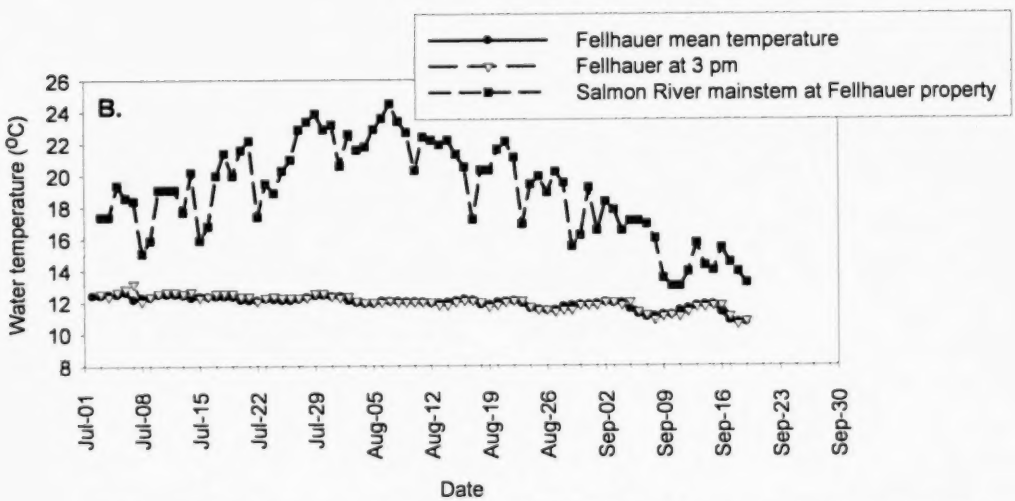


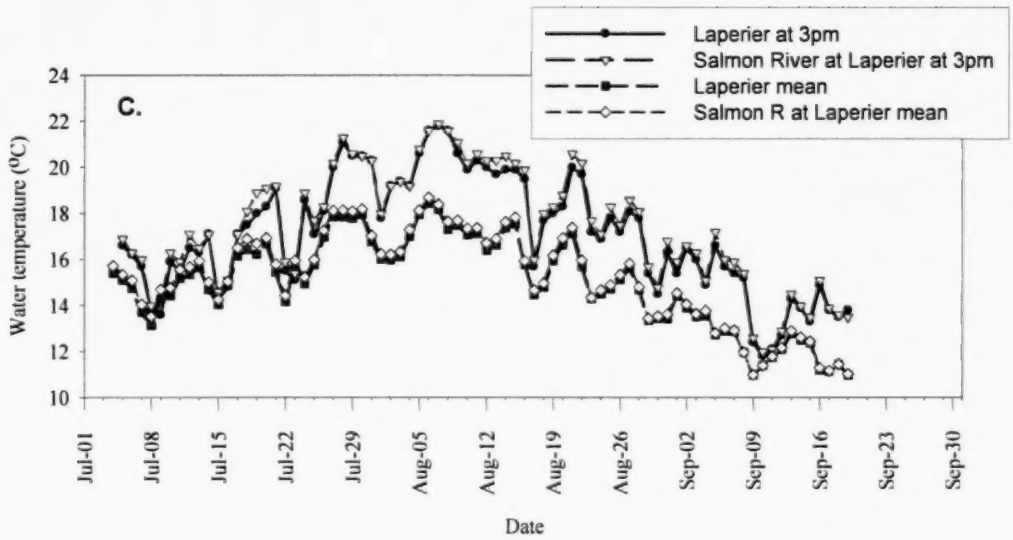
Figure 5 A-G. Time series of water temperatures in select off-channel projects and the receiving water bodies.



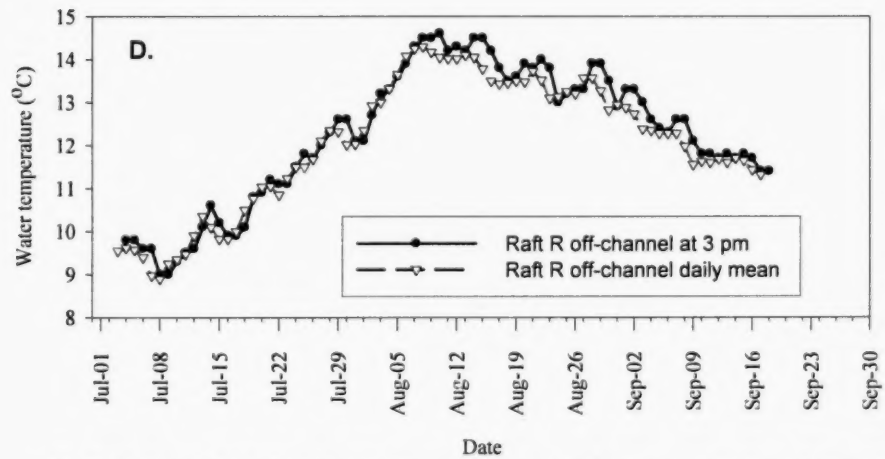
A. Adams River off-channel and mainstem temperatures. Mainstem data is from 2000 for the same date range as the off-channel data.



B. Fellhauer off-channel and nearby Salmon River mainstem water temperatures.

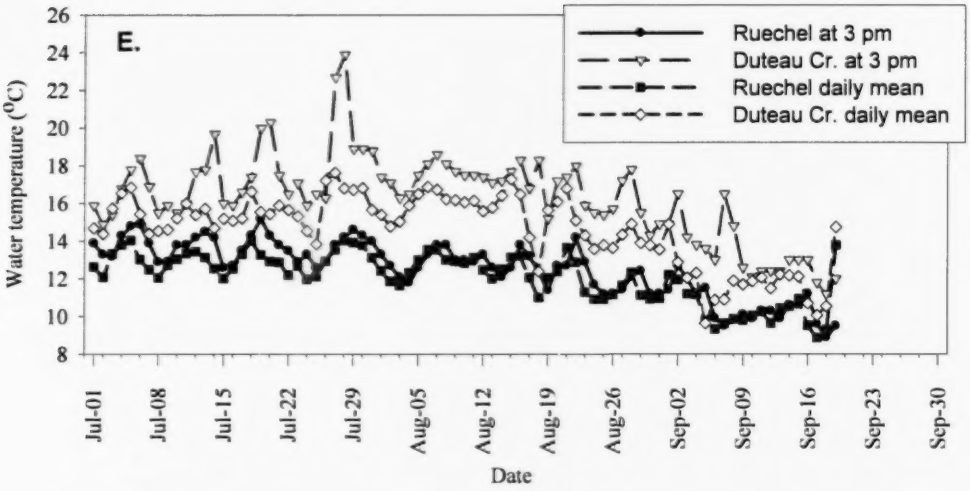


C. Laperier off-channel and nearby Salmon River mainstem water temperatures.

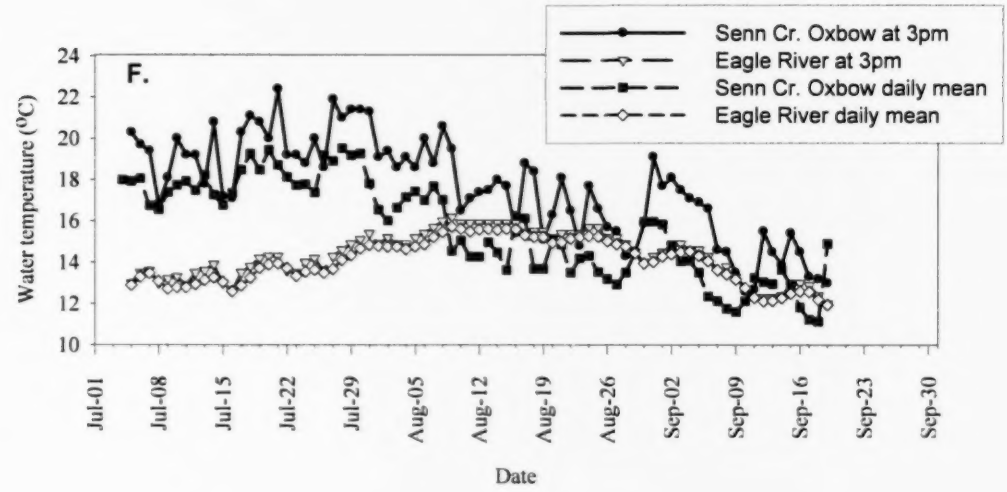


D. Raft river off-channel water temperatures. Raft River mainstem data not available due to theft of temperature logger.

Figure 5 cont.

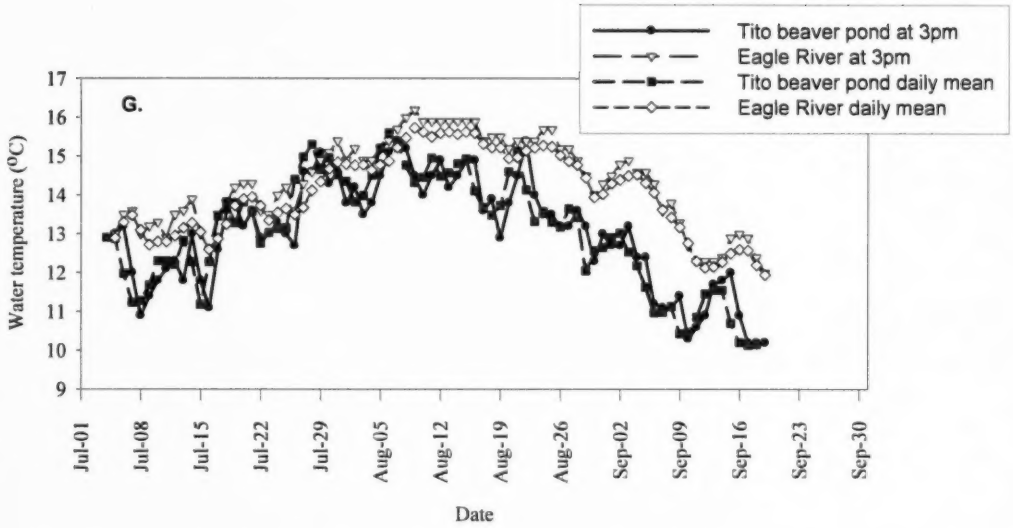


E. Ruechel off-channel and Duteau Creek water temperatures. It is believed the Duteau Creek thermalogger was intermittently exposed to air.



F. Senn Creek oxbow and Eagle River water temperatures. The Senn oxbow temperature logger may have been exposed to air during July.

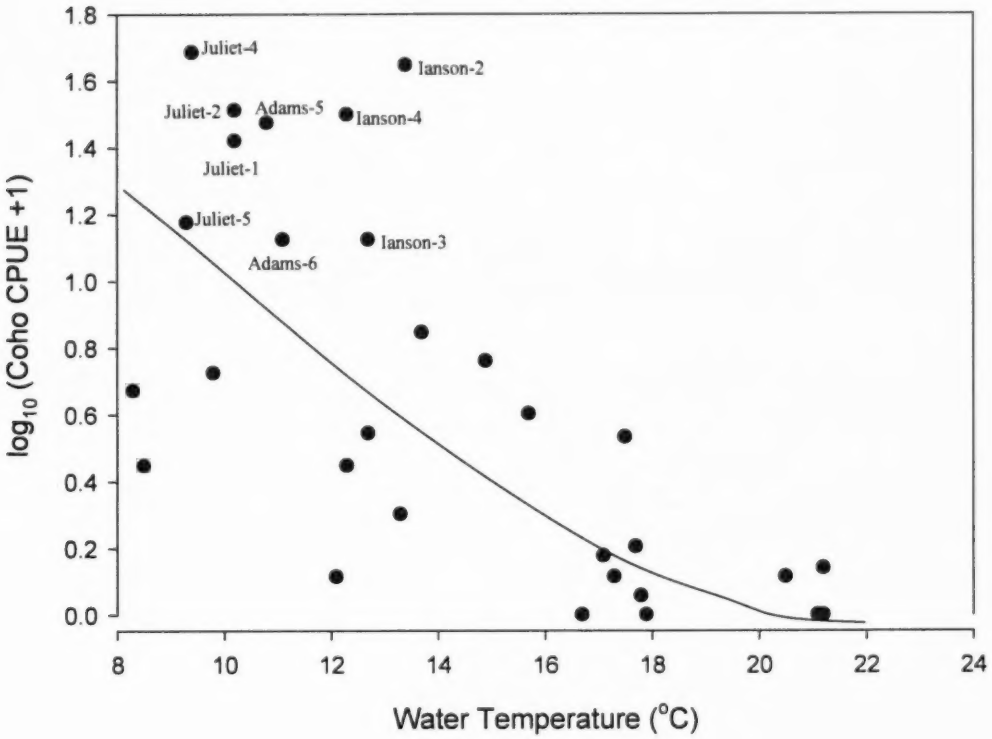
Figure 5. cont.



G. Tito beaver pond off-channel and Eagle River water temperatures.

Figure 5. cont.

Figure 6. Relationship between water temperature and catch per unit effort of coho salmon parr in each zone of the ten off-channels of the study (n=30 zones). Water temperatures are point values collected by a hand held temperature probe at the time Gee traps were deployed. Labels (site name-zone #) are provided for the nine zones with CPUE > 10 coho. Equation of the fitted regression line is $\log_{10}(\text{CPUE} +1) = (1.815 - 0.079 \text{ temperature})^2$ ($r = -0.75$, F ratio = 36.9, $p < 0.0000$).



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